



NORSK POLARINSTITUTT

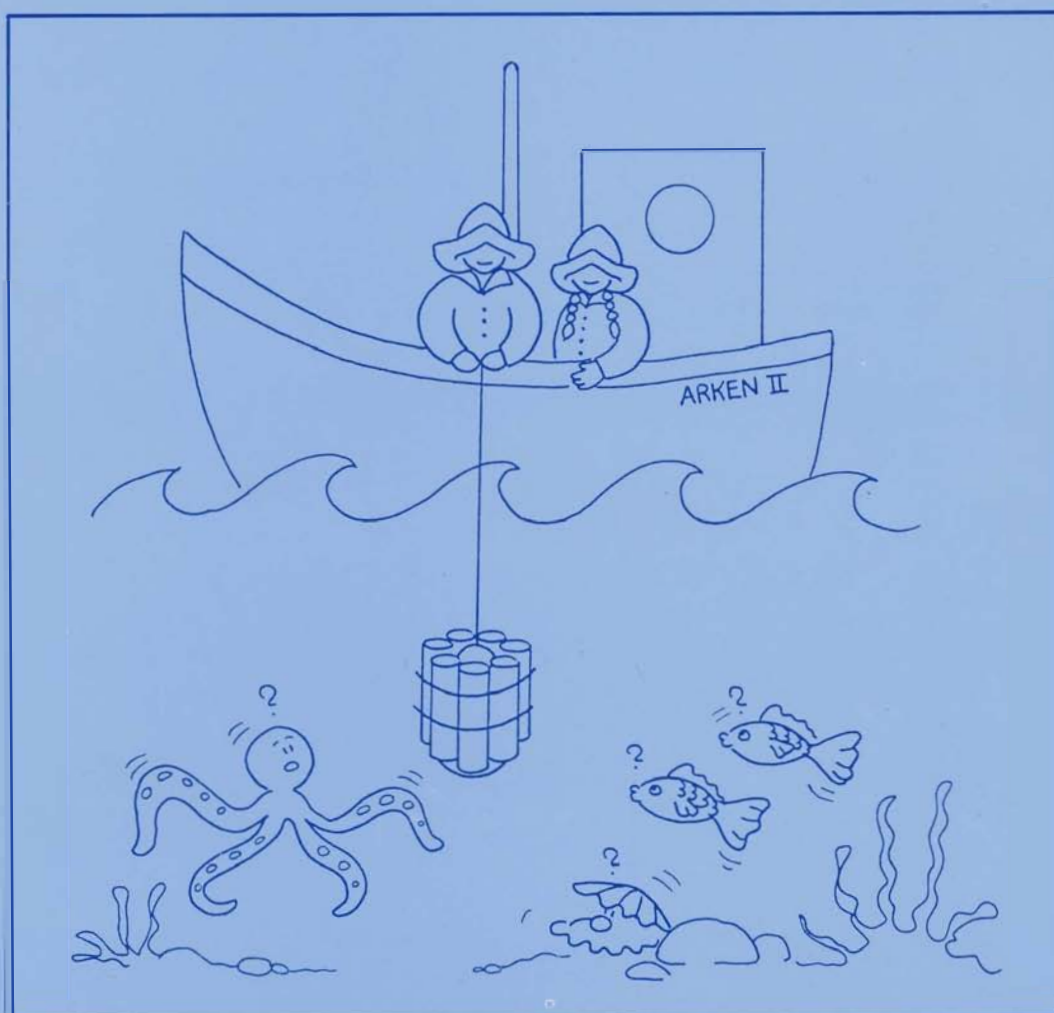
RAPPORTSERIE

NR. 75 - OSLO 1991

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J. BLINDHEIM, A. FOLDVIK, T. VINJE &
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A report on cruise tracks with R/V Lance and
R/V G.O.Sars during July-August 1990





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THE AUTHORS AND THEIR ADRESSES:

- Reidar Nydal** Radiological Dating Laboratory
Dep. of Physics and Mathematics
N-7034 Trondheim, NORWAY
Tlf. +47 7 593308
- Jorunn Gislefoss** Radiological Dating Laboratory
Dep. of Physics and Mathematics
N-7034 Trondheim, NORWAY
Tlf. +47 7 593311
- Ingunn Skjelvan** Radiological Dating Laboratory
Dep. of Physics and Mathematics
N-7034 Trondheim, NORWAY
Tlf. +47 7 593307
(also attached to The Norwegian Polar Research Institute)
- Johan Blindheim** Institute of Marine Research
P.o.box 1870
N-5024 Bergen, NORWAY
Tlf. +47 5 238500
- Arne Foldvik** Geophysical Institute
University of Bergen
Allegt. 70
N-5007 Bergen, NORWAY
Tlf. +47 5 212653
- Torgny Vinje** Norwegian Polar Research Institute
P.O.Box 158
N-1332 Oslo lufthavn, NORWAY
Tlf. +47 2 123650
- Svein Østerhus** Geophysical Institute
University of Bergen
Allegt. 70
N-5007 Bergen, NORWAY
Tlf. +47 5 212607
(also attached to The Norwegian Polar Research Institute)

CONTENTS

INTRODUCTION	5
SAMPLING PROGRAM	6
SAMPLE COLLECTION	8
PREPARATION AND MEASUREMENTS	8
DIC	8
$\delta^{13}\text{C}$	9
$\Delta^{14}\text{C}$	9
OTHER DATA	10
COMMENTS TO THE TABLES AND GRAPHS	10
THE BARENTS SEA	11
THE GREENLAND SEA	11
THE NORWEGIAN SEA	11
ACKNOWLEDGEMENT	12
REFERENCES	13

MEASUREMENTS OF CARBON PROFILES IN THE NORDIC SEAS

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INTRODUCTION

A general fear of a change in the climate has during recent years greatly stimulated research which in some way touches this topic. The research is especially focused on the various climate gases which are poured into the atmosphere at a gradually increasing rate. CO₂ is here the most important contributor to a future heating of the earth. The atmosphere and the ocean are intimately linked, and a permanent temperature change will only occur in a heat balance between the atmosphere and the ocean. The ocean has up to now absorbed about one half of the CO₂ liberated from fossil fuel. The ocean at higher latitudes acts as a sink for CO₂, and it is especially important to observe the uptake of CO₂ and further transport to the deep water in the North Atlantic Ocean. Measurements of CO₂ exchange with the ocean have been supported by circulation studies, where various radioactive and other tracers have been applied (Bard et al. 1987, Heinze et al. 1990, Nydal et al. 1983 and 1984, Peng et al. 1987, Smethie et al. 1986, Schlosser et al. 1991, Østlund et al. 1976, 1984 and 1987, Aagaard et al. 1985).

A study of CO₂ uptake by the ocean in the Norwegian and Greenland Seas was performed in 1989 with the research vessels Håkon Mosby and G.O. Sars (Nydal 1991). The main goal of this study was to obtain information about the penetration of bomb ¹⁴C into the deep ocean, as a part of a circulation study. The experience from 1989 was a guidance for a more extended carbon program in 1990, which included ¹⁴C, ¹³C, Dissolved Inorganic Carbon (DIC) and several hydrographic data. All the results from the cruises which are dealing with the carbon measurements are given in the present report.

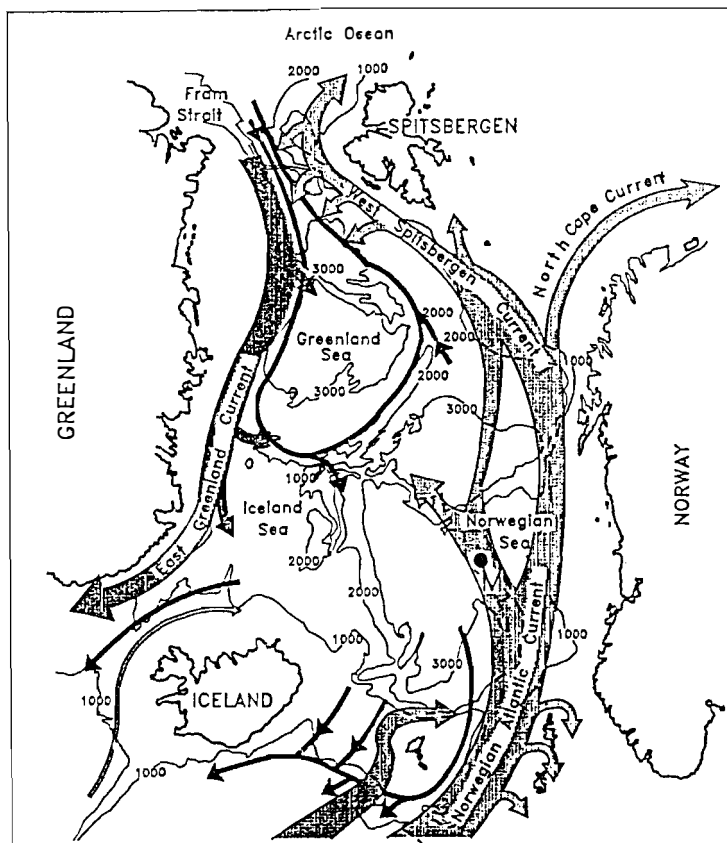


Fig. 1 Map showing the main water circulations in the Nordic Seas.

SAMPLING PROGRAM IN 1990

The CO₂ program in 1990 was performed using the research vessels G.O.Sars and Lance in the Norwegian, Greenland and Barents Seas (Fig.1 and Fig. 2). Here it was possible to include quantitative measurements of DIC, ¹⁴C, and ¹³C in several standard profiles, as well as measurements of temperature and conductivity (salinity) etc.

The cruise with the research vessel Lance was a part of the Soviet Norwegian Oceanographic Program (SNOP) in the Barents Sea, the Fram Strait and the Greenland Sea. Carbon measurements in the northern Barents Sea were done at 5 stations (LA1, 2, 3, 4, 5) in the region 77°43'N to 80°31'N. The Fram Strait and the Greenland Sea were also covered with 5 stations (LA7, 8, 9, 10, 11) between 74°59'N and 79°27'N, and 29°12'E to 32°30'E. All stations, except LA1 and LA4, were CTD (Conductivity, Temperature, Depth) stations during the SNOP cruise, and the corresponding station numbers are given in the tables. During this cruise it was possible, at the LA10 station, to repeat a GEOSECS profile from 1972 (STA 17 in Østlund et al. 1976).

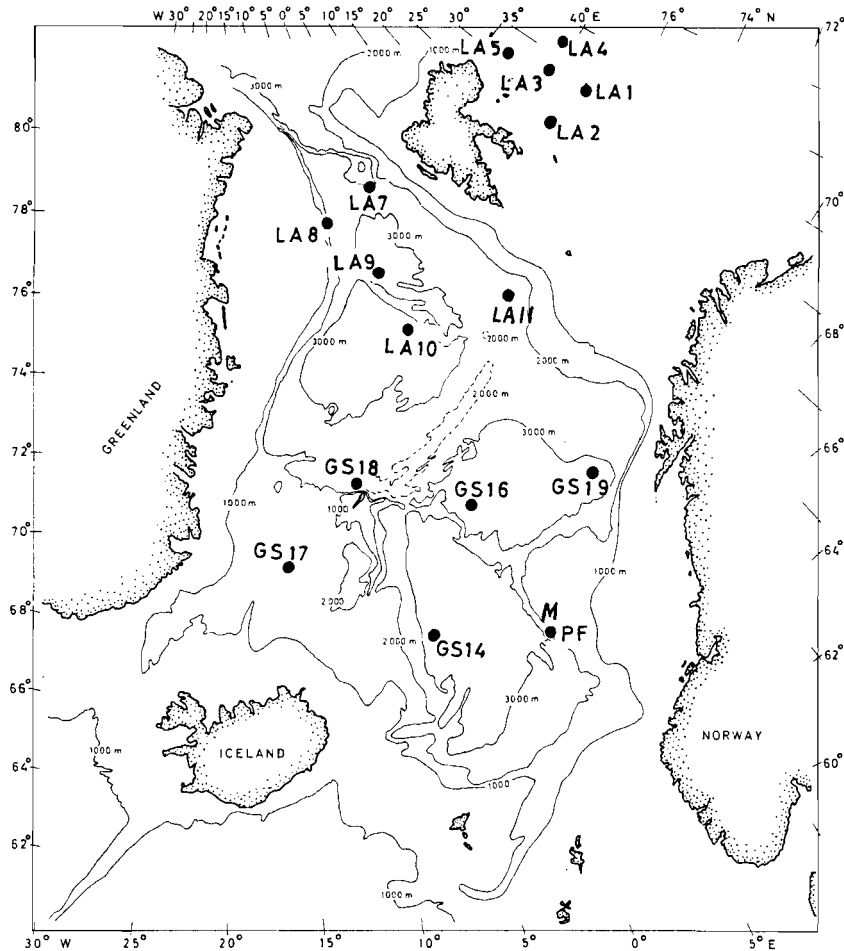


Fig. 2 Locations of the profiles collected from R/V G.O.Sars (GS) and R/V Lance (LA) summer 1990. Station PF (M) was obtained from R/V POLARFRONT, and not included in this report).

Together with the stations covered by Lance, a series of carbon profiles were obtained simultaneously with G.O. Sars (GS14, 15, 16, 17, 18, 19) during a fishery cruise across the Norwegian Sea between 67°00'N and 71°08'N, and 9°36'E to 14°50'W. All stations, except the surface station GS15, were identical with the standard CTD stations (see Tables). During this cruise it was also possible, at the GS16 station, to repeat measurements performed at the GEOSECS station no 18 in 1972 (STA 18 in Østlund et al. 1976).

SAMPLE COLLECTION

During the SNOP cruise, samples were collected for measurements of DIC, pH, ^{14}C , ^{18}O , ^{13}C , ^3H , and ^3He in various profiles. The samples collected with G.O.Sars in the Norwegian Sea were analyzed for DIC, pH, ^{14}C and ^{13}C . Vertical profiles of temperature and conductivity were obtained using a Neil Brown CTD probe. A frame with 12 bottles (each of 2.5 liter) for water sampling was connected to the CTD. Except for conventional ^{14}C measurements, the amount of water in each bottle (sampler) was in general sufficient for the present carbon measurements. The water samples were transferred to one liter glass bottles, and stored at low temperature ($2-4^\circ\text{C}$) until further treatment. No poison was added to the samples, as done by others (Bard et al. 1987).

The large water samples for conventional ^{14}C -measurements were collected with 30 l Niskin bottles and 60 l Go-Flo bottles (General Oceanics), and the water was filled into 200 l, nitrogen filled, steel drums. A main problem with these samples was the long time needed for the collection.

PREPARATION AND MEASUREMENTS

DIC.

The extraction of DIC as CO_2 from 0.5 liter seawater, was carried out on board the ship shortly after collection. A bubbling procedure with nitrogen as a carrier gas, in a closed cycle, was applied for this purpose. The sample was acidified in advance with phosphoric acid to a pH value of ca 1.5. The bubbling lasted for 45 minutes, a time which is in excess of what is strictly needed. The water was removed from the CO_2 -gas using two vapor traps (-80°C) and a drying agent, P_2O_5 . CO_2 was continuously trapped with liquid nitrogen (-196°C) during the cycle. After the flushing was finished, nitrogen was removed, and a quantitative measurement of the CO_2 gas was performed. The obtained accuracy (standard error) in a single measurement, derived from measurement of 6 identical samples, was found to be 0.6%, a result which may be further improved. In single cases it is apparent that greater error may have occurred. The obtained CO_2 gas (ca 25 ml per sample) was sufficient for both ^{13}C and ^{14}C AMS measurements. The present procedure for DIC extractions is developed at the Radiological Dating Laboratory.

$\delta^{13}\text{C}$

The $\delta^{13}\text{C}$ symbol is expressed with the equation:

$$\delta^{13}\text{C} = \frac{R_{\text{sa}} - R_{\text{st}}}{R_{\text{sa}}} \cdot 1000$$

where $R_{\text{sa}} = {}^{13}\text{C}/{}^{12}\text{C}$ for sample
 $R_{\text{st}} = {}^{13}\text{C}/{}^{12}\text{C}$ for standard

$\delta^{13}\text{C}$ is the difference in per mill between the ${}^{13}\text{C}/{}^{12}\text{C}$ ratio in the sample and the international Belemnite standard (PDB).

An amount of 5 ml CO_2 was used for a $\delta^{13}\text{C}$ measurement, performed with a mass spectrometer at the Geological Institute, University of Bergen. This stable isotope is also important as a tracer in the study of carbon exchange, as we here obtain the true ${}^{13}\text{C}/{}^{12}\text{C}$ ratio of the DIC fraction in the samples. The accuracy in each measurement is about 0.1‰.

$\Delta^{14}\text{C}$

Conventional ${}^{14}\text{C}$ measurements were performed at the Radiological Dating Laboratory in Trondheim, and are based on a CO_2 amount of 3-6 liter. This amount was extracted from 100 to 200 liters of seawater on board the ship immediately after collection. A flushing procedure with nitrogen as a carrier gas was applied after adding phosphoric acid to a pH-value of about 3.0. The circulation was performed with an aquarium pump in a closed cycle, where CO_2 was trapped as Na_2CO_3 in one liter 2% sodium hydroxide (NaOH) solution. CO_2 was further released by acid treatment in the laboratory.

Conventional ${}^{14}\text{C}$ measurements were performed by beta counting of ${}^{14}\text{C}$ in CO_2 proportional counters, with effective volume ranging between 1 and 2 liter. The ${}^{14}\text{C}/{}^{12}\text{C}$ ratio of the seawater samples was measured relative to a recent standard. The final result was corrected for fractionation error and given in per mill excess above normal level ($\Delta^{14}\text{C}$) according to the equation (Stuiver and Polach 1977):

$$\Delta^{14}\text{C} = \delta^{14}\text{C} - 2 (\delta^{13}\text{C} + 25) \left(1 + \frac{\delta^{14}\text{C}}{1000}\right)$$

Accelerator Mass Spectrometry (AMS), on small CO₂ samples, were applied for most of the ¹⁴C measurements, which were performed at the University of Arizona. Samples of 1-2 ml CO₂ are converted to CO over hot Zn, and the CO is further reduced to graphite over an iron catalyst at 625°C (Slota et al. 1987). The graphite powder is pressed into an aluminum target holder for the AMS analysis. The present measurements are based on the ¹⁴C/¹³C ratio which is compared to known standards. Final precision in the isotope ratio measurement is about ± 0.6% for a measuring time of 50 minutes per sample. One half of the AMS samples was measured with about this accuracy. The other half was measured with an accuracy of ca 0.4 %, using 3 accelerator targets. Complete details of the experimental procedures are given by Linick et al. (1986), and of the calculation by Donahue et al. (1990).

OTHER DATA

pH measurements were performed with an Orion Research digital pH/temperature meter - model 221, and a Ross combination pH electrode - 8165BN. The pH meter has an accuracy of ca 0.03 pH-units, but there is need for a pH meter with better accuracy. It is important to perform the pH measurements as soon as possible after sample collection in order to avoid the influence of any biological effects, and hence the measurements were done on board the ships.

Samples in the Greenland and Barents Seas were also collected for analysis of tritium, helium and oxygen. Measurements of dissolved oxygen, based on Winklers method, were performed on board.

Vertical profiles of temperature and conductivity (salinity) were obtained using a Neil Brown CTD probe and on-line computing facilities. All the sensors of the CTD were subject to regular laboratory calibration prior to and after the cruise. The temperature sensors have an accuracy of 0.005°C. Calibration of the salinity data was performed by on-shore analysis of watersamples taken from various depths. The absolute accuracy of the salinity is assumed to be better than 0.005 psu (practical salinity units). With respect to the accuracy of the pressure, laboratory calibration shows that the specification of ± 0.1% at full pressure scale (6500 mm Hg) is maintained (Foldvik et al. 1991).

COMMENTS TO THE TABLES AND GRAPHS

Tables and graphs for each specific station are shown on two adjacent pages in this report. The station number (emphasized) for each carbon profile contains two letters which identify the research vessel (e.g. LA: Lance). There are also an other station number (Sta no.), which is connected to the corresponding CTD station of the cruise. The CTD station number is given in order to have access to the hydrographical data.

THE BARENTS SEA

Carbon measurements in the northern Barents Sea were performed on 5 stations (LA1, 2, 3, 4, 5), where only LA2, 4 and 5 are deep sea profiles. The stations are located on the shelf, with depth down to ca 300 m. This small depth has made collection of large samples relatively easy, and conventional ^{14}C technique has thus been applied for all samples, except for LA3-5, where a large sample was lost. The $\Delta^{14}\text{C}$ values are very alike in both horizontal and vertical direction (50-60 ‰), and indicate a relatively rapid vertical mixing of the water. As concerns the $\delta^{13}\text{C}$ measurements, there are only slight differences between the values for the LA2 and LA3 profiles, except for the extreme value in the LA2-5 sample. An unreliable value may have occurred by a fractionation accident during the treatment of this sample.

As concerns the DIC values in depth profiles, the unexpected deviations for sample LA3-5 and LA3-6 may have been caused by unknown errors during the sample treatment.

THE GREENLAND SEA

The Greenland Sea was covered by the 5 stations LA7, 8, 9, 10 and 11. After an ordinary treatment of the DIC samples at station LA7 on board the ship, we run out of dry-ice for the vapor traps, and the routine for the later samples was changed. The station LA7 is influenced by waters of Atlantic origin, carried by the West Spitsbergen Current. This is reflected both in the temperature and the ^{14}C curves for the upper ca 500 m. There are, however, no ^{14}C measurements between depths of 500 m and 1000 m which could give more details about the transition down to the deeper layers. It is also a general experience from the cruise that carbon isotopes have to be measured at shorter depth intervals.

Moving westward to station LA8 in the East Greenland Current, a few conventional ^{14}C data indicate a more rapid exchange from the surface to the deeper layers. A better documented ^{14}C profile of similar shape was found (LA10) in the central Greenland Sea. The DIC samples at station LA8 were treated on board, but the CO_2 gas was intermediately absorbed in a 2% NaOH solution. DIC samples at the other stations in the Greenland Sea (LA9, 10, and 11) were all stored as sea water at low temperature (2-4°C) until later treatment in the laboratory. According to the tables, the delay in treatment varies from 0.5 to 1.5 months, a storage time which may have some influence (bacterial action) in samples in the upper layers.

THE NORWEGIAN SEA

A study on the storage time for the DIC samples was performed at station GS19 in the Norwegian Sea. A series of samples was here measured immediately after collection, and a parallel series was stored 4 to 5 months before treatment. It turned out that the stored samples normally had slightly higher DIC values (see figure). This was also the case for three other parallel samples (GS16-2) at station GS16. The difference in DIC values between the stored and unstored samples was unexpectedly small for such a long period.

A careful study of the influence of storage at shorter intervals is, however, necessary. The DIC profiles, GS16, GS17 and GS19 turn out to be very similar, and they should be reliable within their limit of error. For the other profiles, GS14 and GS18, the storage time of seawater before treatment was 2 to 3 months, and may have resulted in slightly higher DIC values. The last two profiles show, however, no systematic difference from the other profiles in the Norwegian Sea.

The shape of the three ^{14}C profiles, GS14, GS16 and GS19, across the Norwegian Sea was largely influenced by the inflowing Atlantic water. This is reflected in the temperature curves and the ^{14}C curves. The relatively long plateau at ca 1000 m depth (i.e. the approximately horizontal part of the $\Delta^{14}\text{C}$ curve, see figure) indicates a slow exchange between surface and deeper layer. For the two other profiles (GS17 and GS18), which were worked out in the Central Iceland Sea and in the Jan Mayen Fracture Zone, the shape is approaching those in the Northern Greenland Sea. Three samples (GS16-5, GS17-9 and GS18-7b) shows, however, $\Delta^{14}\text{C}$ values which are not representative for the sea in this area. These samples must in some way have been contaminated with atmospheric CO_2 during the flushing procedure (leakage?). This conclusion was confirmed with a control measurement of sample GS18-7b, which gave a $\Delta^{14}\text{C}$ value (GS18-7a), which seems to be more in agreement with the other values in this profile.

ACKNOWLEDGEMENT

The present carbon work in the Nordic Seas was performed in a collaboration between the Institute of Marine Research, Bergen, the Norwegian Polar Research Institute, Oslo, the Geophysical Institute, University of Bergen, and the Radiological Dating Laboratory, Trondheim, which have all given financially and technically support. We want to thank the captains and crews of the research vessels G.O.Sars and Lance. The AMS measurements of ^{14}C were kindly performed by Douglas Donahue and Timothy Jull, the University of Arizona. The measurements were in part supported by grant (EAR 88-22292) from the U.S. National Science Foundation. Thanks are due also to Eystein Jansen, Geological Institute, University of Bergen, for performing the ^{13}C measurements. Financial support from the Norwegian Ministry of the Environment and the Norwegian Research Council for Science and the Humanities are also gratefully acknowledged.

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Position: 78°12.00'N 29°50.00'E

LA2

Sta.no. 11 R/V Lance

Sample no.	Depth m	Temp. °C	Salinity psu	pH	O ₂ ml/l	DIC(CO ₂) mmol/kg	δ ¹³ C ‰	Δ ¹⁴ C ‰
LA2-1	8	3.469	33.582	8.22	8.33	1.958	2.091	
LA2-2a	50							64.2 ± 4.6 T
LA2-2b	58.5	-1.685	33.996	8.06	7.84	2.071	0.996	
LA2-3	100							55.5 ± 4.4 T
LA2-4	154.5	0.783	34.612	8.07	6.97	2.113	1.022	
LA2-5	200	1.276	34.717	8.15	6.72	2.103	1.898	48.2 ± 4.2 T
LA2-6	235.5	1.168	34.759	8.06	6.85	2.161	0.918	
LA2-7a	300							60.1 ± 3.6 T
LA2-7b	307.5	0.813	34.896	7.65	8.98	2.107	0.669	

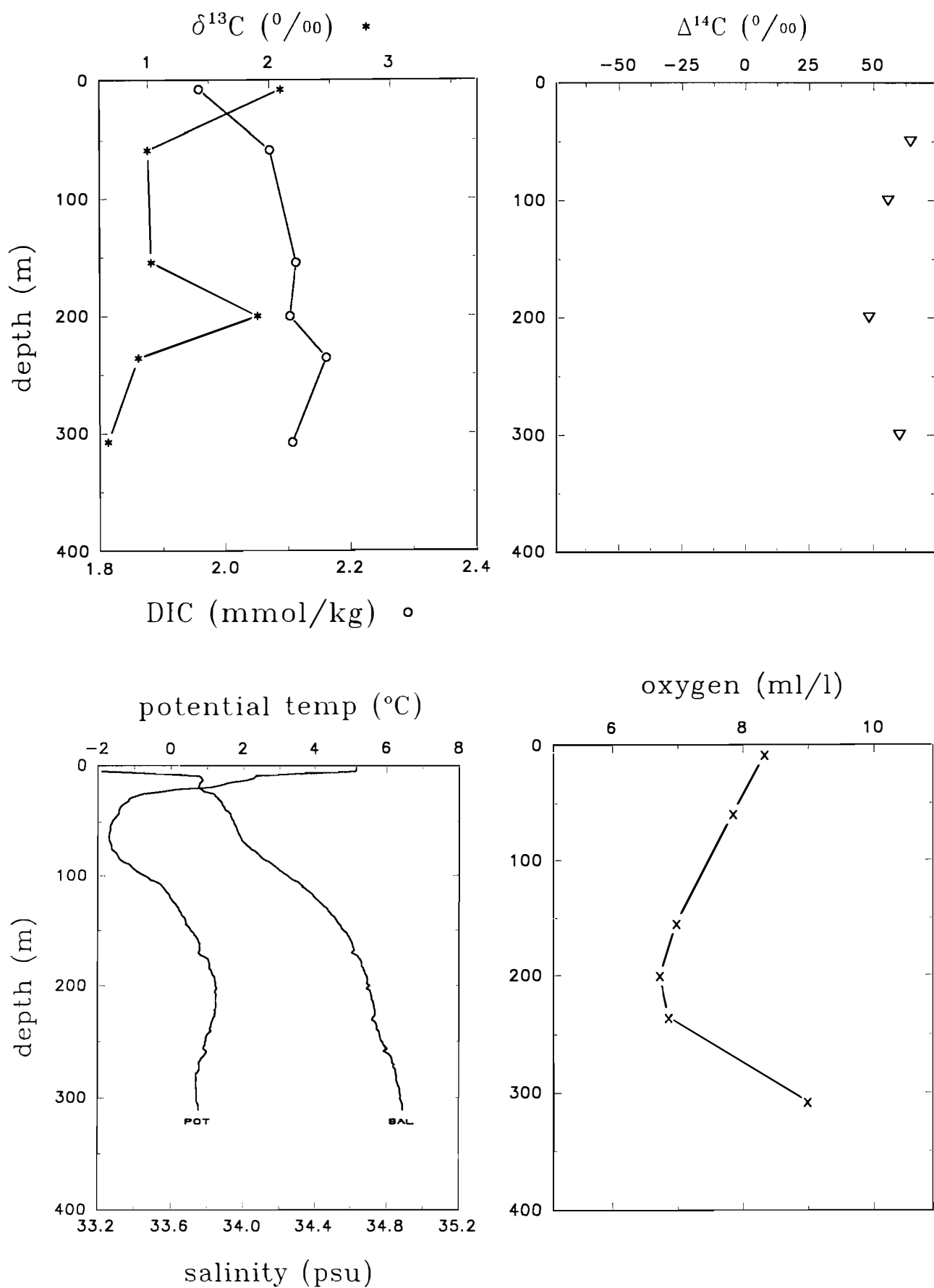
T - conventional, Trondheim.

Position: 78°12.00'N 29°50.00'E

July 23, 1990

Bottom depth: 311 m

LA2



Position: 79°22.00'N 30°20.00'E

LA3

Sta.no. 34 R/V Lance

Sample no.	Depth m	Temp. °C	Salinity psu	pH	O ₂ ml/l	DIC(CO ₂) o mmol/kg	δ ¹³ C ‰	Δ ¹⁴ C ‰
LA3-1	6	4.804	33.683	8.15	7.80	1.962	2.254	61.0 ± 4.2 T
LA3-2	11	1.241	33.967	8.29	8.50	1.970		
LA3-3	30.5	-1.063	34.013	7.84	7.87	2.027	1.221	65.9 ± 3.8 T
LA3-4	100	-0.265	34.409	8.12	7.45	2.076		
LA3-5	140	0.684	34.574	8.00	7.31	1.987	0.861	56.3 ± 4.1 AA
LA3-6	240	-0.095	34.613	7.98	7.58	2.038	1.161	66.4 ± 4.8 T
LA3-7	278	0.537	34.697	8.09		2.104		
LA3-8a	309.5	1.062	34.769	8.04	6.96	2.125		
LA3-8b	313							44.6 ± 3.6 T

o - precipitation of CO₂ in NaOH was preformed for the samples LA3-2, -4 and -7.

T - conventional, Trondheim.

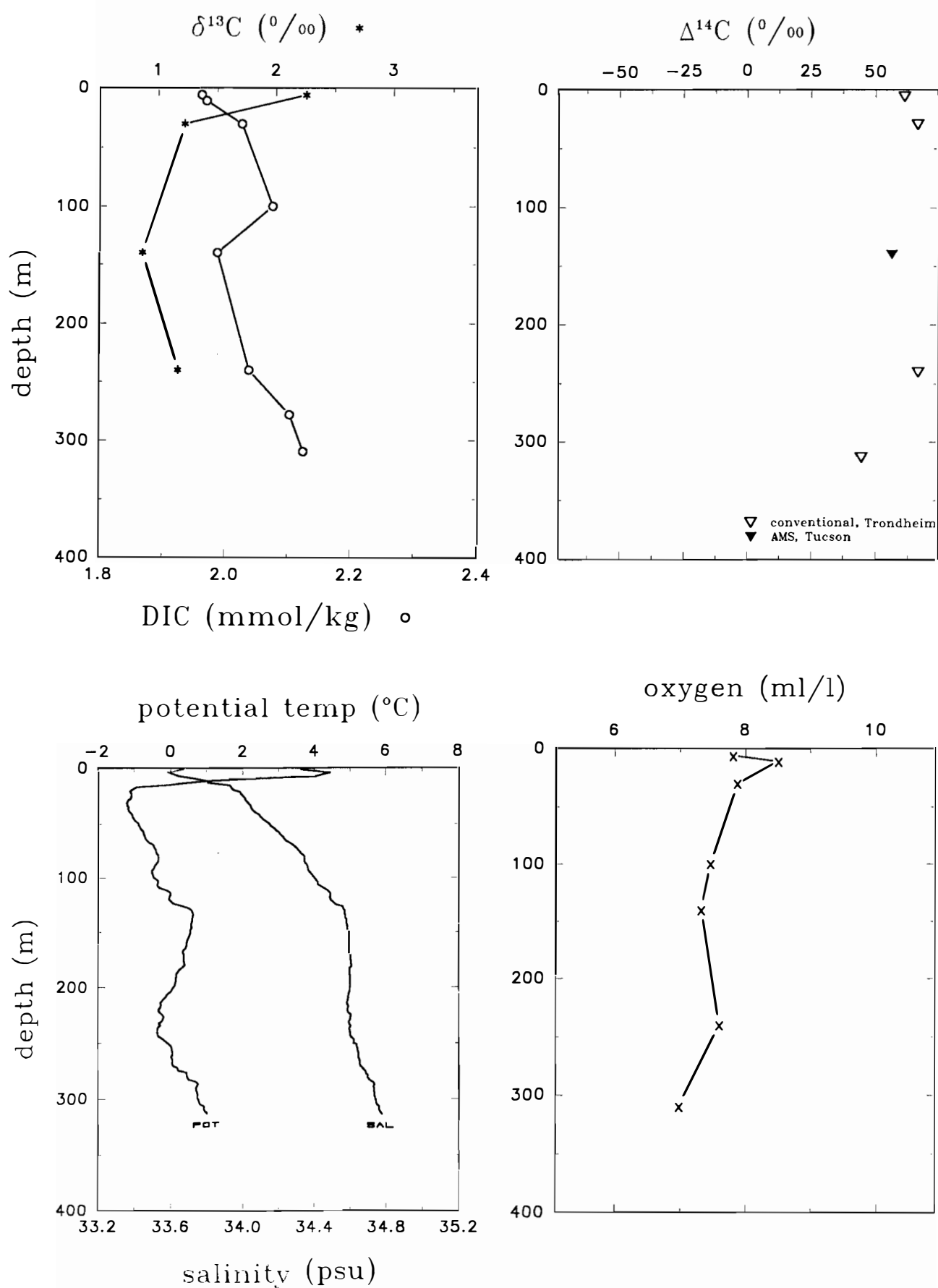
AA - AMS, Tucson.

Position: 79°22.00'N 30°20.00'E

July 25, 1990

Bottom depth: 319 m

LA3



Position: 80°31.00'N 29°12.00'E

LA5

Sta.no. 49 R/V Lance

Sample no.	Depth m	Temp. °C	Salinity psu	pH	O ₂ ml/l	DIC(CO ₂) o mmol/kg	δ ¹³ C ‰	Δ ¹⁴ C ‰
LA5-1	0	-1.085	33.428		9.38			
LA5-2a	5							61.8 ± 3.6 T
LA5-2b	7	-1.077	33.629	8.08	9.38	1.973	1.723	
LA5-2c	7	-1.077	33.629		9.33			
LA5-3	17	-1.182	33.816	8.26	9.02			
LA5-4	31.5	-1.550	34.011	8.18	8.42			
LA5-5a	50							41.3 ± 4.9 T
LA5-5b	55.5	-0.996	34.253	8.14	8.00			
LA5-6a	100							54.6 ± 4.5 T
LA5-6b	105	0.223	34.608	8.11	7.58			
LA5-7a	200							53.7 ± 4.5 T
LA5-7b	203.5	0.822	34.708	8.12	7.30			
LA5-8a	334				6.51			41.5 ± 5.9 T
LA5-8b	354	1.028	34.735	8.13	7.37			

o - precipitation of CO₂ in NaOH was preformed for all samples, except LA5-2b.

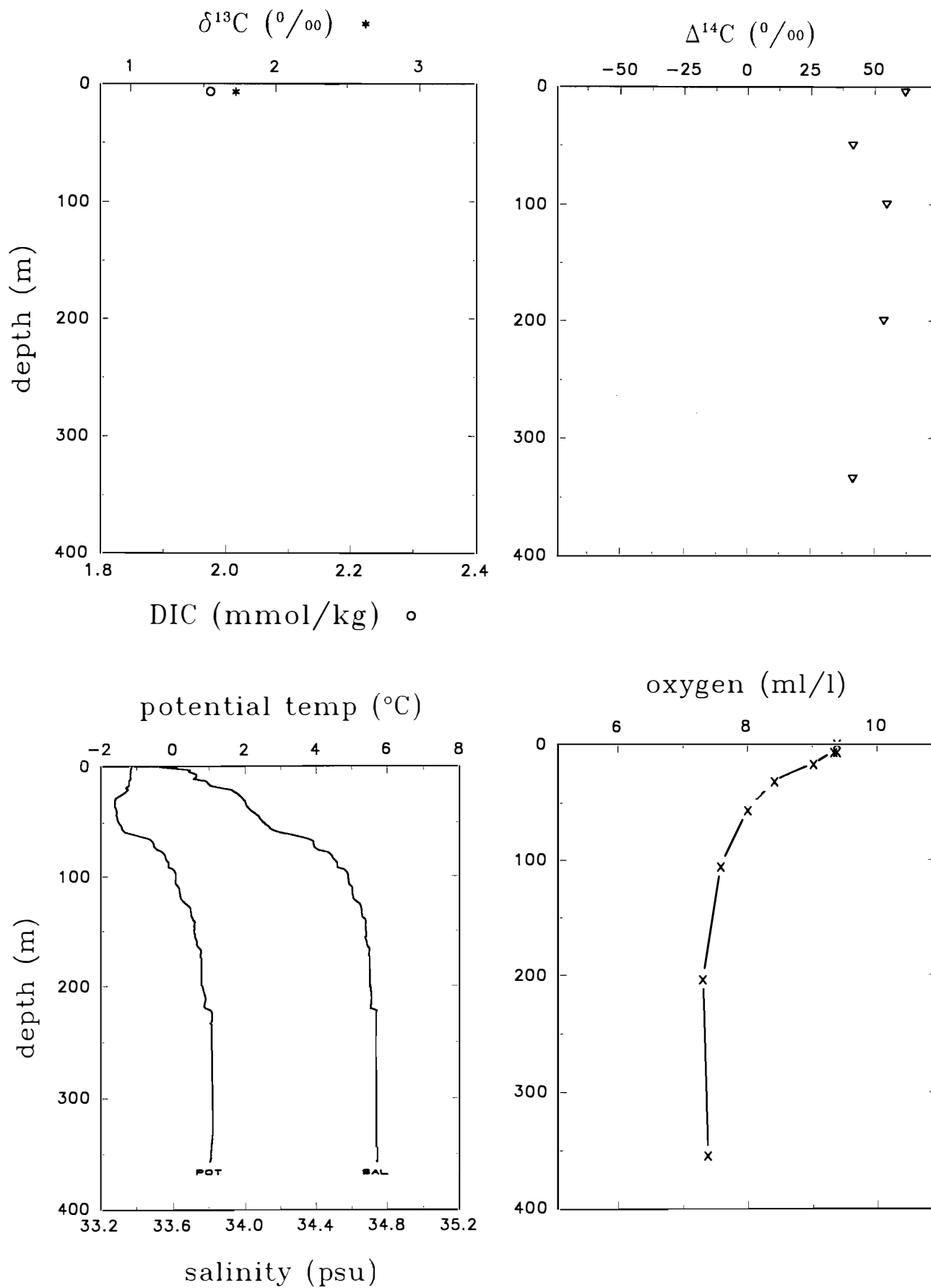
T - conventional, Trondheim.

Position: 80°31.00'N 29°12.00'E

July 30, 1990

Bottom depth: 355 m

LA5



Position: 79°27.07'N 05°51.51'E

LA7

Sta.no. 57 R/V Lance

Sample no.	Depth m	Temp. °C	Salinity psu	pH	O ₂ ml/l	DIC(CO ₂) mmol/kg	δ ¹³ C ‰	Δ ¹⁴ C ‰
LA7-1	5	5.016	33.480	8.34	7.65	1.925	2.153	61.9 ± 4.6 T
LA7-2	47.5	4.210	35.020	8.22	7.42	2.037	1.333	56.2 ± 7.0 AA
LA7-3	99	3.559	35.026	8.12	7.14	2.001	1.035	49.3 ± 4.4 T
LA7-4	292.5	2.729	35.015	8.14	7.16	2.086	1.191	44.7 ± 4.5 T
LA7-5	493	0.996	34.939	8.13	7.09	2.110	1.057	56.7 ± 6.9 AA
LA7-6	993	-0.725	34.906	8.12	7.03	2.099	1.216	-34.5 ± 6.6 AA
LA7-7	1180	-0.870	34.904	7.99	6.92	2.104	1.239	-26.3 ± 5.9 AA
LA7-8	1477	-0.943	34.905	7.99	7.11	2.073	1.166	-36.7 ± 6.2 AA
LA7-9	1936	-0.964	34.906	7.98	7.12	2.049	1.112	-46.3 ± 6.0 AA

T - conventional, Trondheim.

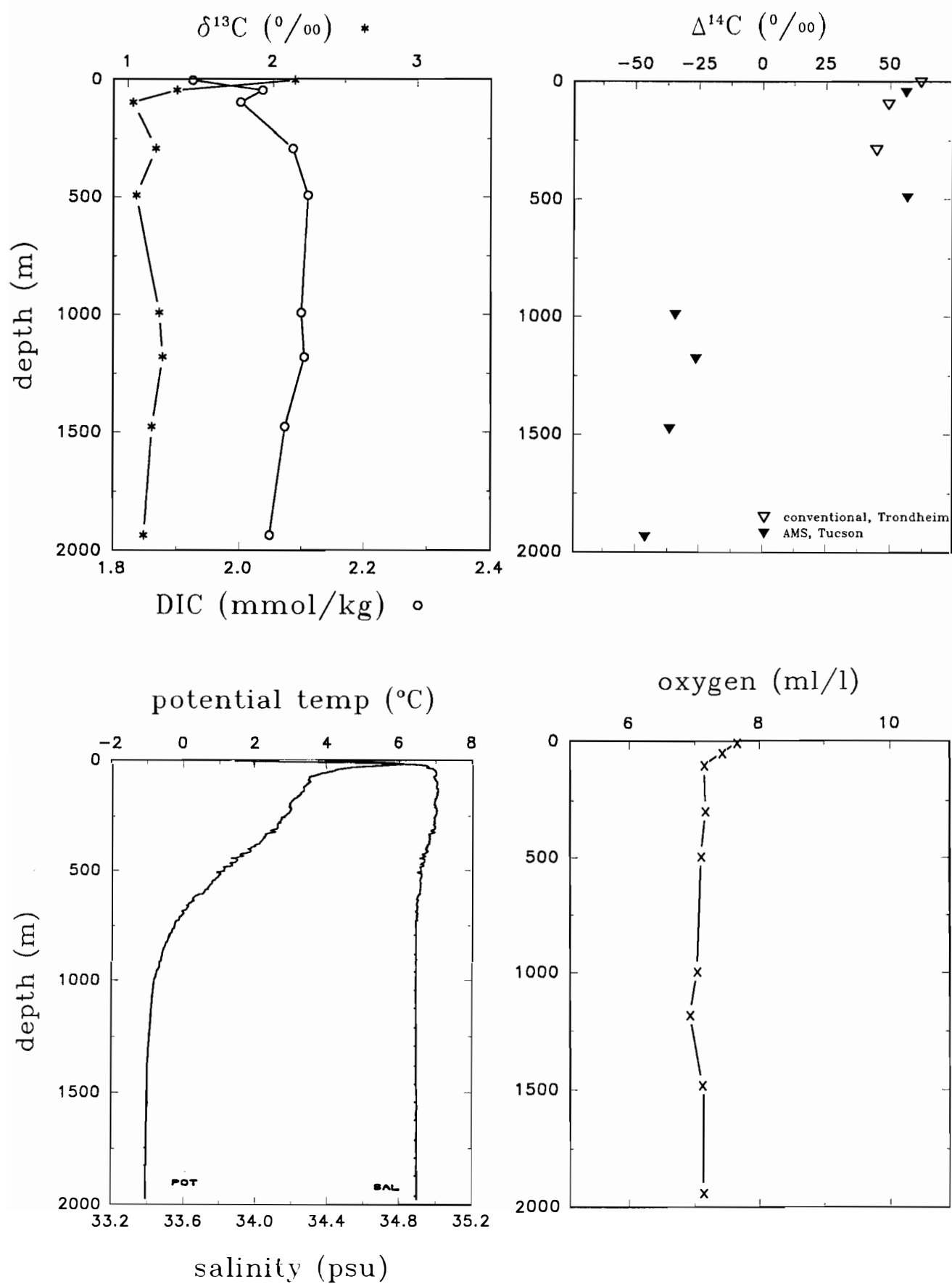
AA - AMS, Tucson.

Position: 79°27.07'N 05°51.51'E

Aug 3, 1990

Bottom depth: 2010 m

LA7



Position: 78°52.40'N 04°06.20'W

LA8

Sta.no. 64/65 R/V Lance

Sample no.	Depth m	Temp. °C	Salinity psu	pH	O ₂ ml/l	DIC(CO ₂) o mmol/kg	δ ¹³ C ‰	Δ ¹⁴ C ‰
LA8-1	3	-0.685	30.472					
LA8-2a	5	-0.757	30.564	8.12	8.89	1.855	1.829	77.6 ± 6.1 T
LA8-2b	5	-0.757	30.564			1.928		
LA8-3	11	-1.053	31.371					
LA8-4	24.5	-1.699	32.235	8.06	6.83	2.138		
LA8-5	101	-1.815	33.878	8.05	7.85	2.116		70.1 ± 5.5 T
LA8-6	200	2.389	34.813	8.07	7.04	2.089		
LA8-7	299.5	2.714	34.892	8.06	7.02	2.156		
LA8-8	397.5	2.482	34.952	8.05	7.06	2.095		44.4 ± 4.5 T
LA8-9	501	1.706	34.924	8.04	7.19			
LA8-10	600.5	1.328	34.914	8.03	7.04			
LA8-11	800	0.403	34.884	8.03	7.33	2.148		
LA8-12	999	0.029	34.892	8.02	7.02			
LA8-13	1188	-0.226	34.900	8.01	6.25	2.124		
LA8-14	1481	-0.381	34.916	8.02	6.85			
LA8-15a	1818.5	-0.594	34.927	8.01	6.95	2.035	1.264	-31.9 ± 5.0 T
LA8-15b	1818.5	-0.594	34.927			2.257		

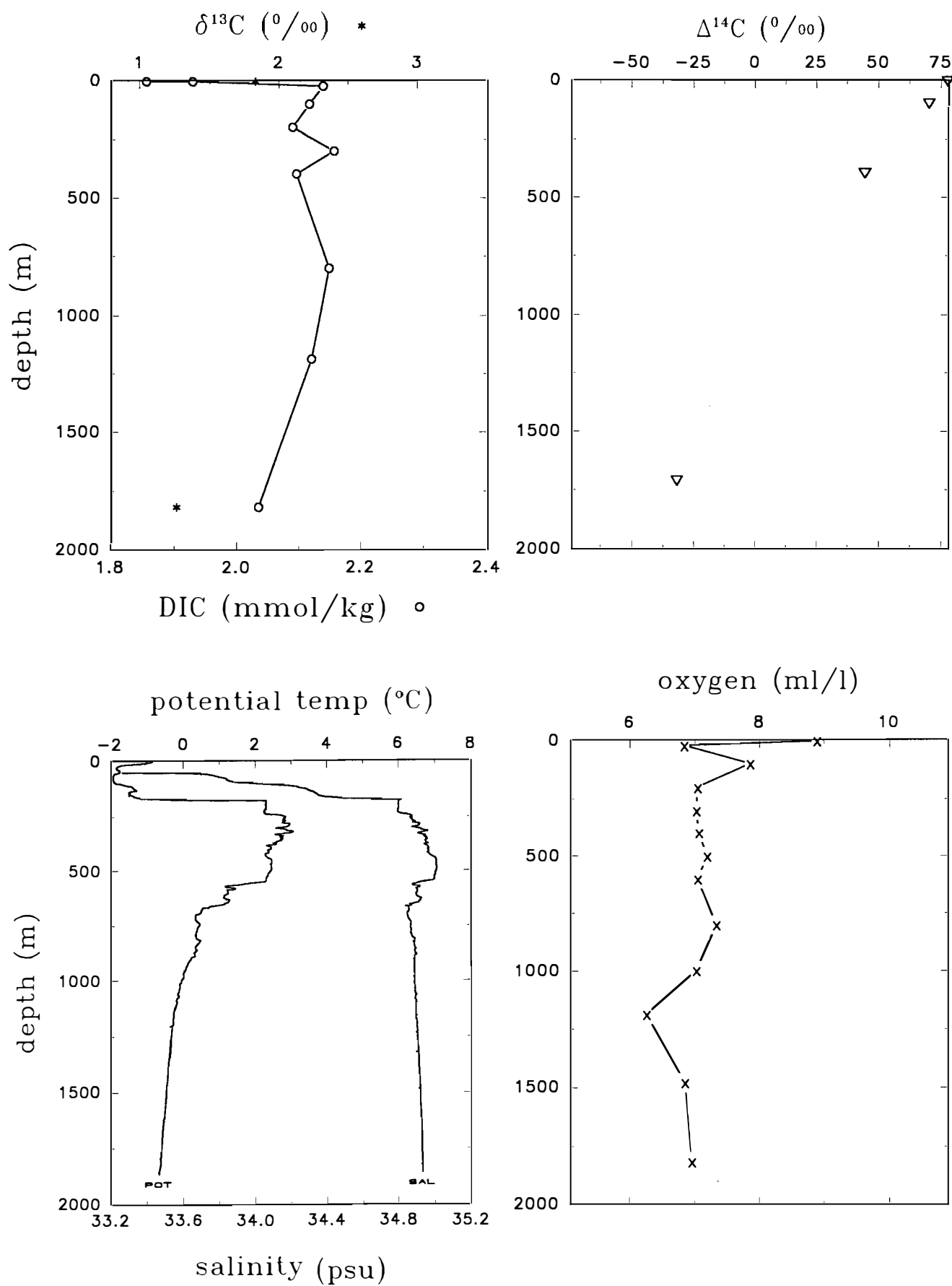
o - precipitation of CO₂ in NaOH was preformed for all samples, except LA8-2a and LA8-15a.

T - conventional, Trondheim.

Position: 78°52.40'N 04°06.20'W

Aug 6, 1990 Bottom depth: 1902 m

LA8



Position: 76°52.70'N 01°34.00'E

LA9

Sta.no. 84 R/V Lance

Sample no.	Depth m	Temp. °C	Salinity psu	O ₂ ml/l	DIC(CO ₂) μmol/kg	δ ¹³ C ‰
LA9-1	6	3.665	32.063	7.86	1.914	1.761
LA9-2	50.5	2.739	34.963	7.25	1.989	1.110
LA9-3	99	2.280	34.970	7.27	2.010	1.141
LA9-4	148.5	1.450	34.920	7.34	2.113	1.217
LA9-5	294.5	-0.074	35.058	7.58	2.011	0.580
LA9-6	590	-0.321	34.879	7.65	2.128	0.828
LA9-7	998	-0.579	34.892	7.37	2.185	0.570
LA9-8	1980.5	-0.968	34.901	7.18	2.129	1.229
LA9-9	3180.5	-1.015	34.900	7.21	2.136	1.135

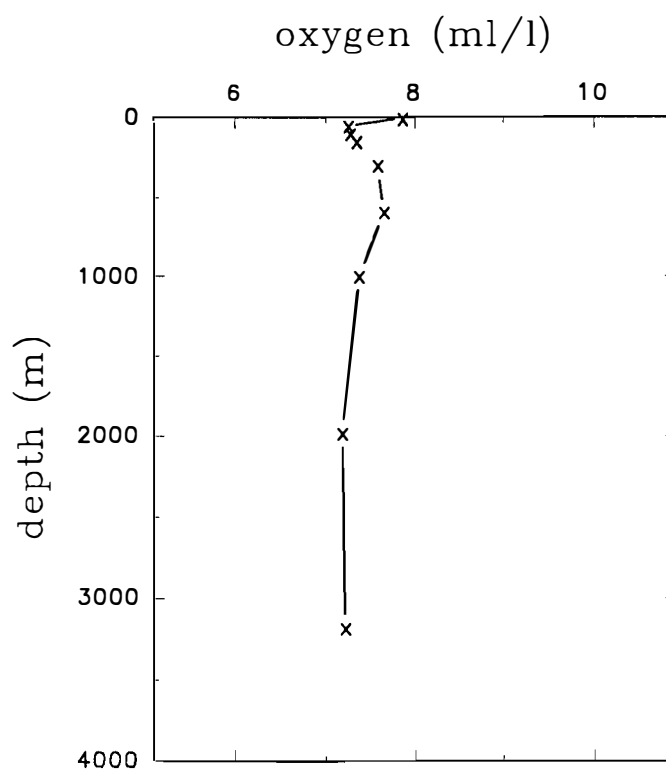
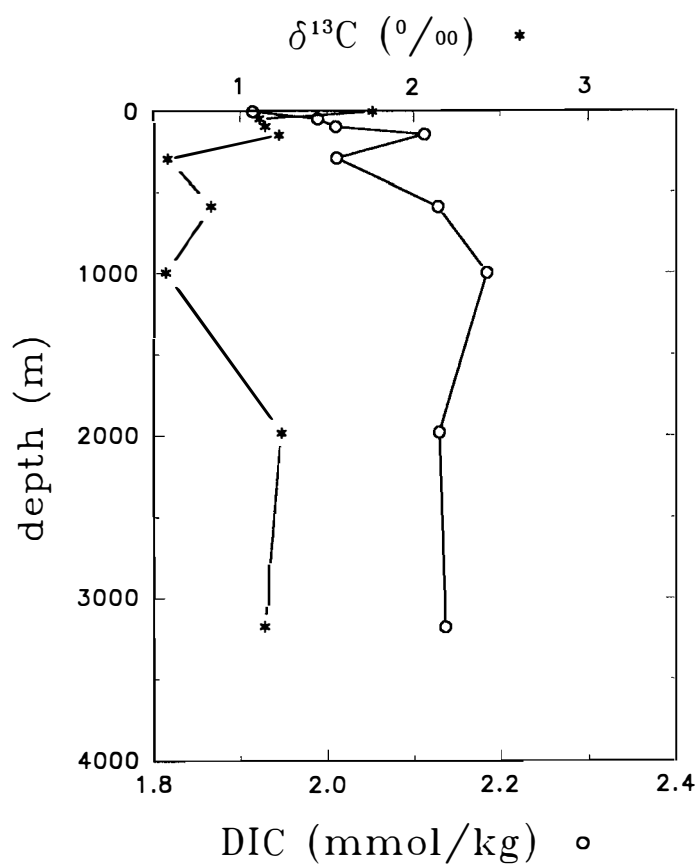
o - seawater stored 14 to 41 days before treatment (DIC).

Position: 76°52.70'N 01°34.00'E

Aug 10, 1990

Bottom depth: 3200 m

LA9



Position: 74°58.88'N 02°28.73'W

LA10

Sta.no. 88 R/V Lance

Sample no.	Depth m	Temp. °C	Salinity psu	O ₂ ml/l	DIC(CO ₂) o mmol/kg	δ ¹³ C ‰	Δ ¹⁴ C ‰
LA10-1	6	4.909	32.086		1.951	1.537	56.1 ± 3.6 T
LA10-2	51.5	-0.933	34.799	7.48	2.065	1.126	31.8 ± 6.3 AA
LA10-3a	101	-1.531	34.799				29.8 ± 4.5 T
LA10-3b	104	-1.439	34.810	8.65	2.128	1.037	
LA10-4	246.5	-1.083	34.855	7.64			
LA10-5	393.5	-0.812	34.882	7.62	2.153	0.937	8.3 ± 3.5 T
LA10-6	590	-0.931	34.884		2.124	0.777	-12.0 ± 6.1 AA
LA10-7	785	-1.023	34.885	7.24	2.079 *	1.004	-18.7 ± 6.0 AA
LA10-8	987.5	-1.071	34.885	7.32	2.113	0.899	-10.4 ± 6.2 AA
LA10-9	1181	-1.091	34.887	7.27	2.117	0.965	-7.8 ± 5.3 T
LA10-10	1968	-1.063	34.895	7.20	2.132	1.035	-37.9 ± 6.9 AA
LA10-11	2454.5	-1.054	34.898	7.13	2.092	1.088	-36.1 ± 6.1 AA
LA10-12	2938	-1.055	34.897	7.12	1.988 *	1.144	-36.0 ± 6.2 AA
LA10-13	3619	-1.013	34.898	7.24	2.054	1.125	-29.8 ± 3.6 T

o - seawater stored 38 to 55 days before treatment (DIC).

♦ - values excluded from the plot because of leakage.

T - conventional, Trondheim.

AA - AMS, Tucson.

Samples collected in Juni/July 1989, R/V Håkon Mosby:

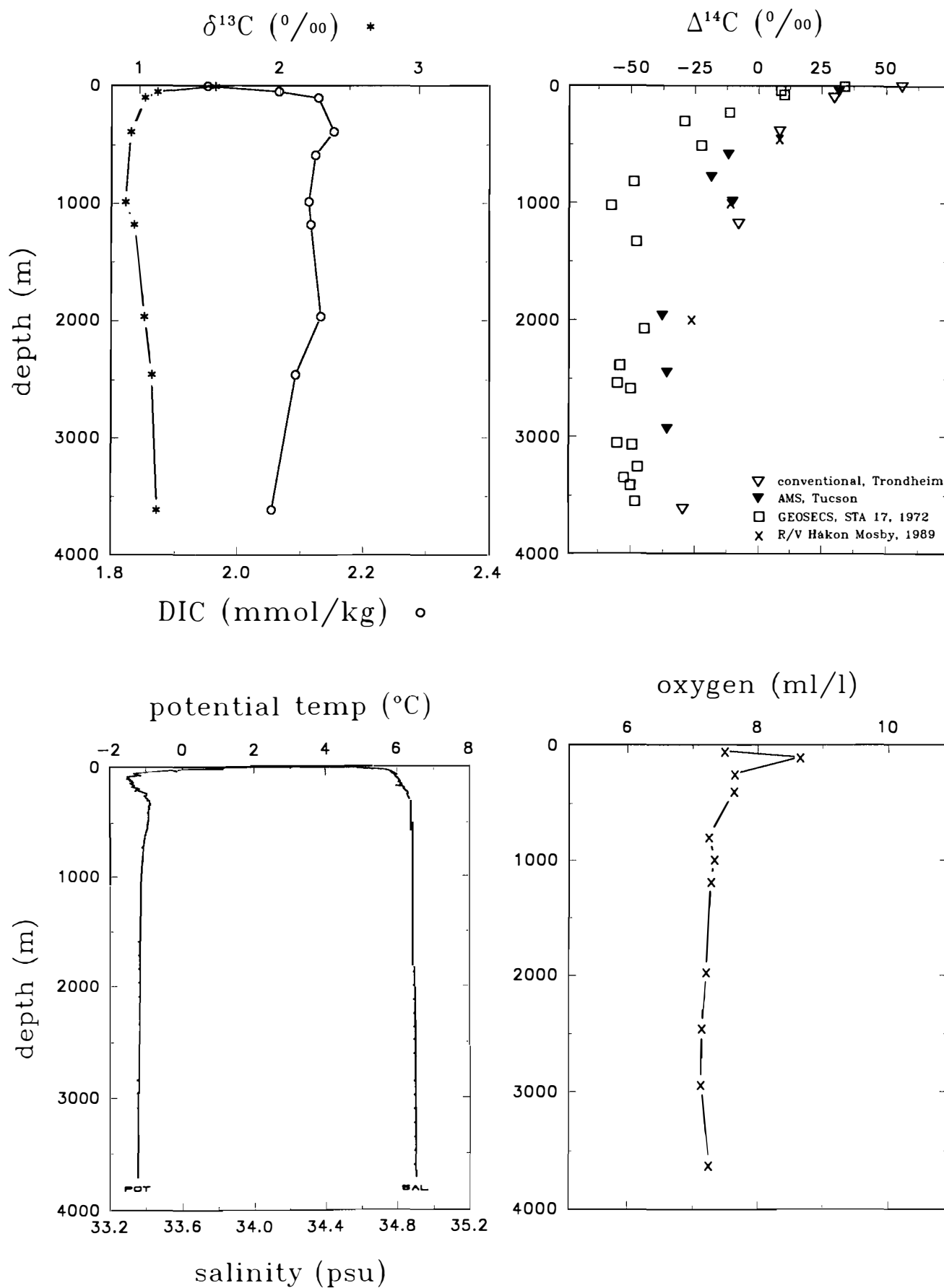
Sample no.	Position	Depth m	Δ ¹⁴ C ‰
MO-4	75°00'N 05°00'W	450	8.1 ± 4.7 T
MO-5	75°00'N 05°00'W	1000	-11.4 ± 4.3 T
MO-6	75°00'N 02°30'W	2000	-26.6 ± 4.7 T

Position: 74°58.88'N 02°28.73'W

Aug 11, 1990

Bottom depth: 3720 m

LA10



Position: 74°28.45'N 11°26.02'E

LA11

Sta.no. 93 R/V Lance

Sample no.	Depth m	Temp. °C	Salinity psu	O ₂ ml/l	DIC(CO ₂) o mmol/kg	δ ¹³ C ‰
LA11-1	5	7.934	35.075	6.89		
LA11-2	101	5.008	35.093	6.82	2.097	0.948
LA11-3	296.5	3.588	35.041	7.10		
LA11-4	593	2.562	35.002	7.21	2.117	1.009
LA11-5	789	0.592	34.917	7.19	2.078	0.843
LA11-6	984.5	-0.288	34.895	7.19	2.125	1.109
LA11-7	1458.5	-0.809	34.904	7.09	2.128	1.095
LA11-8	2311	-0.974	34.904	7.01	2.134	1.722

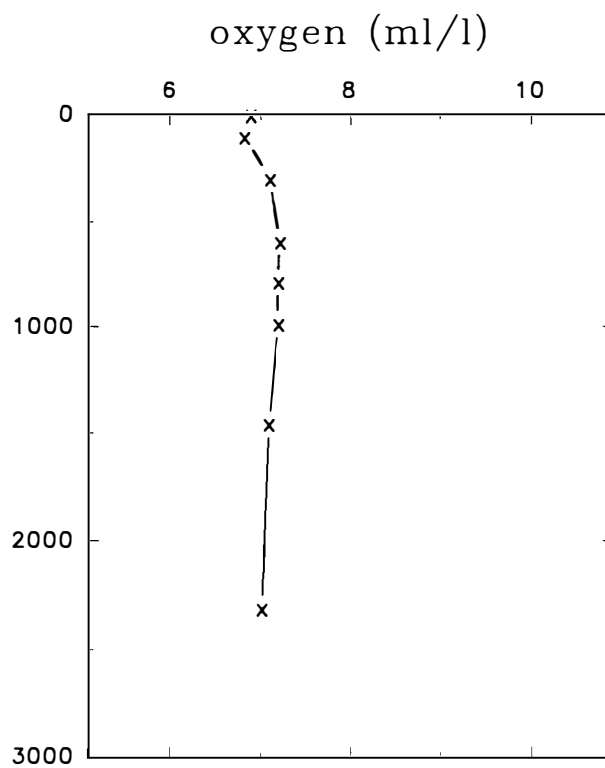
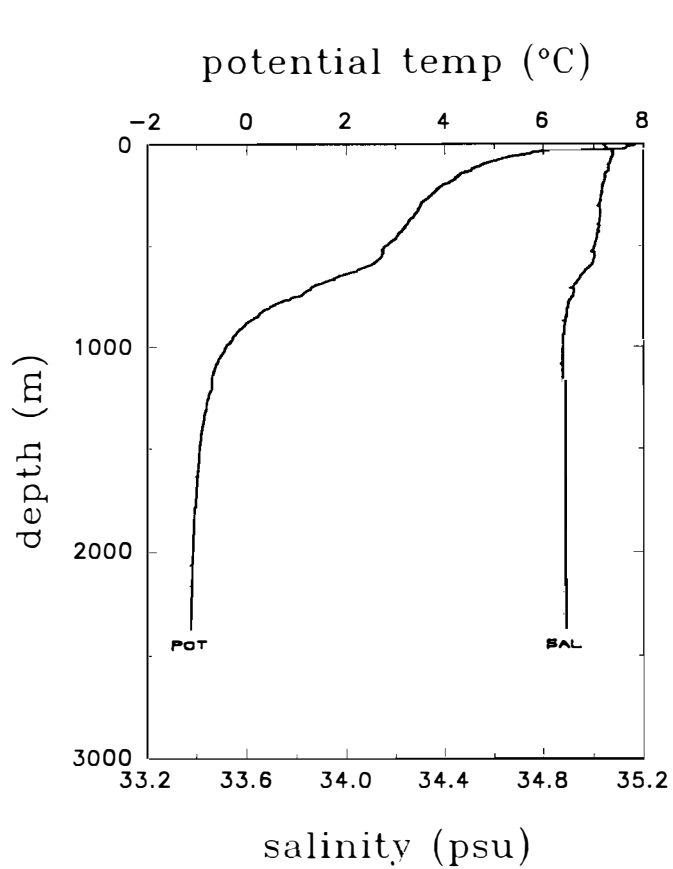
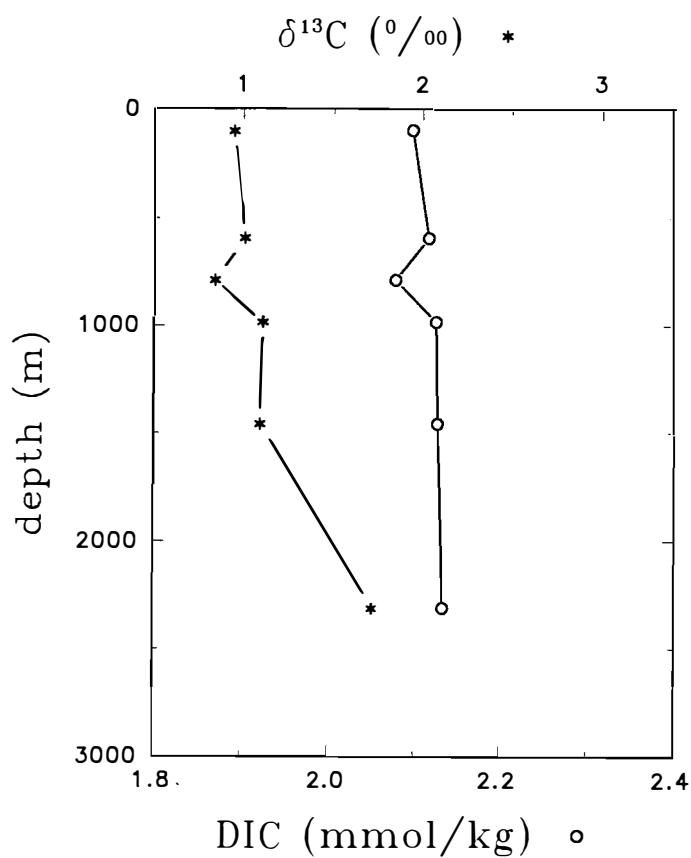
o - seawater stored 26 to 45 days before treatment (DIC).

Position: 74°28.45'N 11°26.02'E

Aug 13, 1990

Bottom depth: 2337 m

LA11



Position: 67°00'N 05°00'W

GS14

Sta.no. 1042 R/V G.O.Sars

Sample no.	Depth m	Temp. °C	Salinity psu	DIC(CO ₂) o mmol/kg	$\delta^{13}\text{C}$ ‰	$\Delta^{14}\text{C}$ ‰
GS14-1	0	9.771	34.948	2.048	1.916	49.7 ± 4.0 AA
GS14-2	10	9.710	34.958	2.079	1.844	41.0 ± 4.0 AA
GS14-3	100	3.930	34.959	2.114	0.953	46.6 ± 4.1 AA
GS14-4	495	0.700	34.883	2.132	1.416	28.2 ± 5.6 AA
GS14-5	790	-0.361	34.882	2.106	0.886	-23.8 ± 3.8 AA
GS14-6	1185	-0.715	34.900	2.134	1.071	-41.8 ± 3.8 AA
GS14-7	1480	-0.829	34.907	2.099	1.144	-42.3 ± 3.8 AA
GS14-8	1970	-0.911	34.910	2.131	1.031	-58.0 ± 4.2 AA
GS14-9	2460	-0.912	34.912	2.188	0.969	-71.1 ± 3.7 AA
GS14-10	2950	-0.876	34.911			

o - seawater stored 30 to 70 days before treatment (DIC).

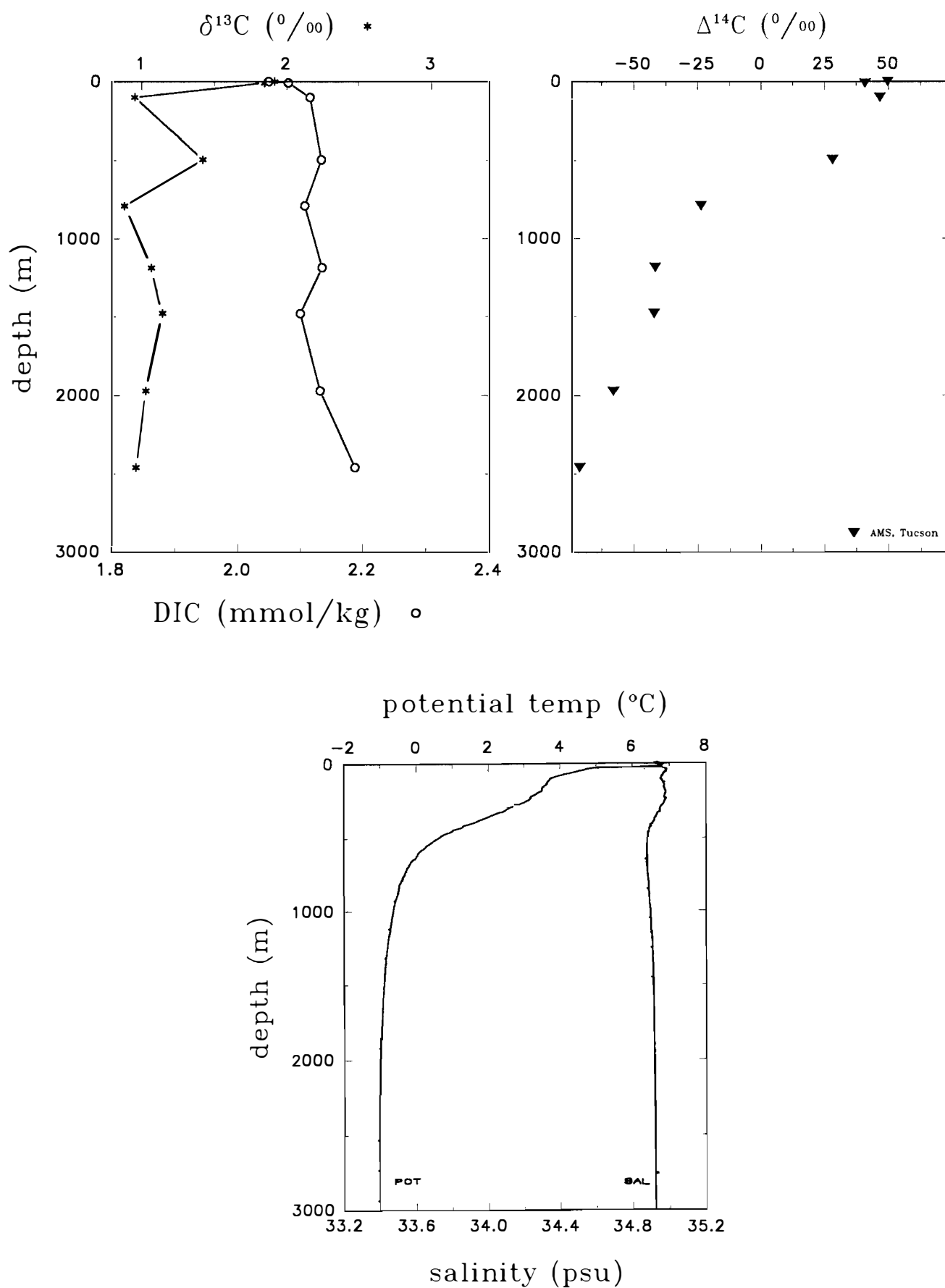
AA - AMS, Tucson.

Position: 67°00'N 05°00'W

July 30, 1990

Bottom depth: 3420 m

GS14



Position: 70°00.11'N 00°00.57'E

GS16

Sta.no. 1070 R/V G.O.Sars

Sample no.	Depth m	Temp. °C	Salinity psu	pH	DIC(CO ₂) mmol/kg	$\delta^{13}\text{C}$ ‰	$\Delta^{14}\text{C}$ ‰
GS16-1	0	10.570	35.108	8.10	2.018	3.113	
GS16-2	4	10.570	35.108	8.07	2.012	2.332	59.0 ± 3.8 T
GS16-3	25	10.388	35.103	8.08	1.984	2.645	58.0 ± 4.8 AA
GS16-4	100	5.856	35.106	7.97	2.083	1.199	49.5 ± 3.8 T
GS16-5	200	5.232	35.082	7.90	2.099	1.135	94.9 ± 5.0 AA *
GS16-6	495	4.136	35.065	7.96	2.091	1.744	46.1 ± 4.4 T
GS16-7	990	0.444	34.903	7.90	2.120	1.184	17.9 ± 5.2 AA
GS16-8	1480	-0.621	34.909	7.88	2.114	1.320	-19.3 ± 6.3 AA
GS16-9	1970	-0.831	34.914	7.89	2.109	1.392	-52.0 ± 6.2 AA
GS16-10	2460	-0.895	34.914	7.90	2.129	1.378	-48.5 ± 6.4 AA
GS16-11	3046	-0.868	34.911	7.90	2.135	1.369	-57.9 ± 6.0 AA

♦ - value out of range.
T - conventional, Trondheim.
AA - AMS, Tucson.

Three parallel samples of GS16-2 were stored and measured after 79 to 176 days:

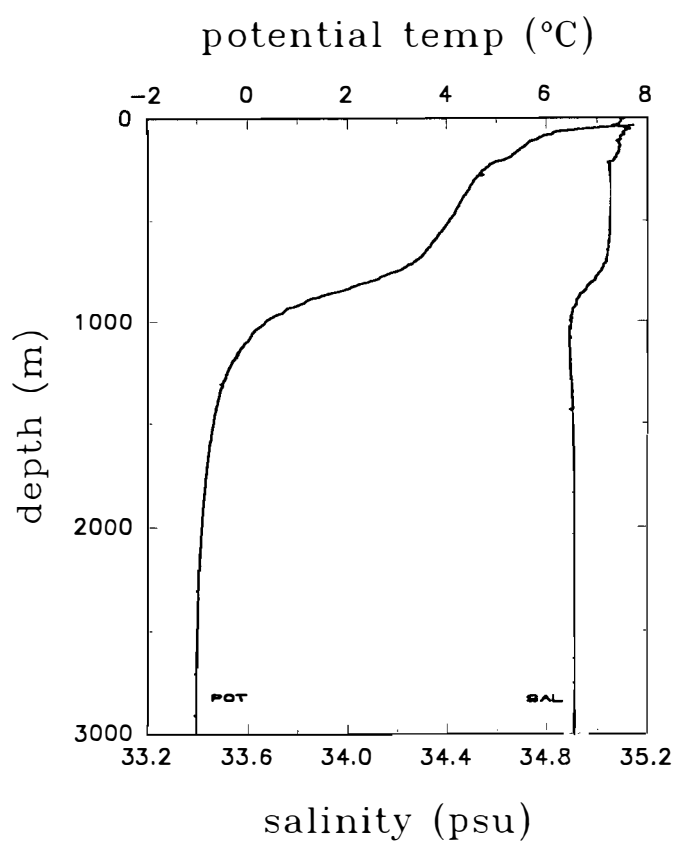
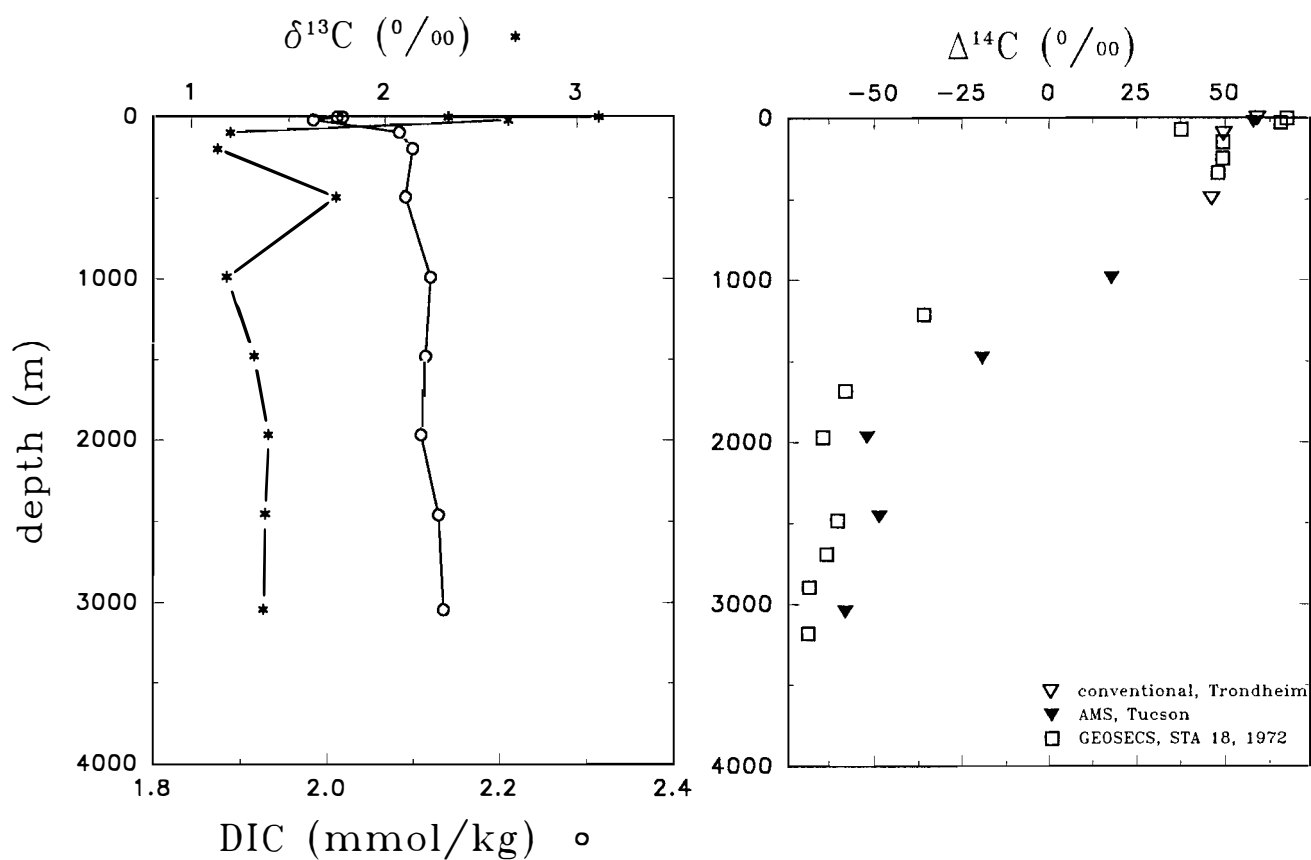
Sample no.	Depth m	Stored before treatment days	DIC(CO ₂) mmol/kg
GS16-2	4	79	2.042
		176	2.086
		176	2.085

Position: 70°00.11'N 00°00.57'E

Aug 7, 1990

Bottom depth: 3250 m

GS16



Position: 69°30.54'N 14°49.84'W

GS17

Sta.no. 1078 R/V G.O.Sars

Sample no.	Depth m	Temp. °C	Salinity psu	pH	DIC(CO ₂) mmol/kg	δ ¹³ C ‰	Δ ¹⁴ C ‰
GS17-1	0	6.172	34.545	8.04	2.003	2.252	
GS17-2	5	5.981	34.721				52.1 ± 4.0 T
GS17-3	10	5.973	34.719	8.06	2.040	3.049	45.7 ± 3.7 AA
GS17-4	25	5.644	34.694	8.02	2.021	2.233	42.1 ± 4.1 AA
GS17-5	50	1.863	34.782	7.93	2.088	1.617	40.3 ± 3.9 AA
GS17-6	100	0.280	34.809	7.92	2.105	1.234	45.0 ± 4.5 T
GS17-7	200	0.004	34.814	7.91	2.116	1.411	42.7 ± 3.6 AA
GS17-8	395	0.184	34.891	7.89	2.125	1.205	25.9 ± 4.0 AA
GS17-9	690	-0.363	34.907	7.95	2.082	1.568	45.6 ± 4.0 AA
GS17-10	1135	-0.701	34.912	7.90	2.114	1.295	-30.2 ± 3.5 AA
GS17-11	1332	-0.765	34.912	7.87	2.117	1.236	-45.7 ± 3.7 AA

T - conventional, Trondheim.

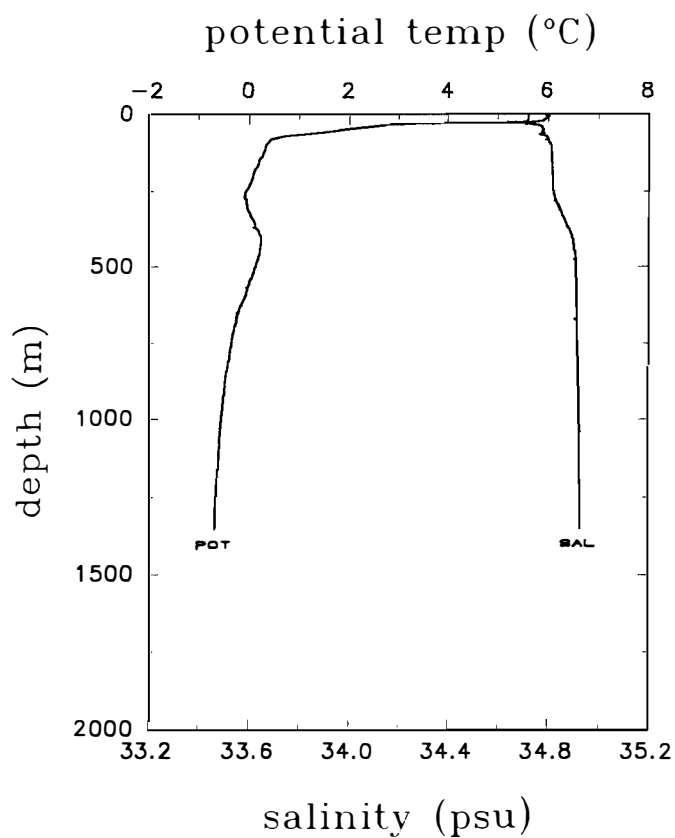
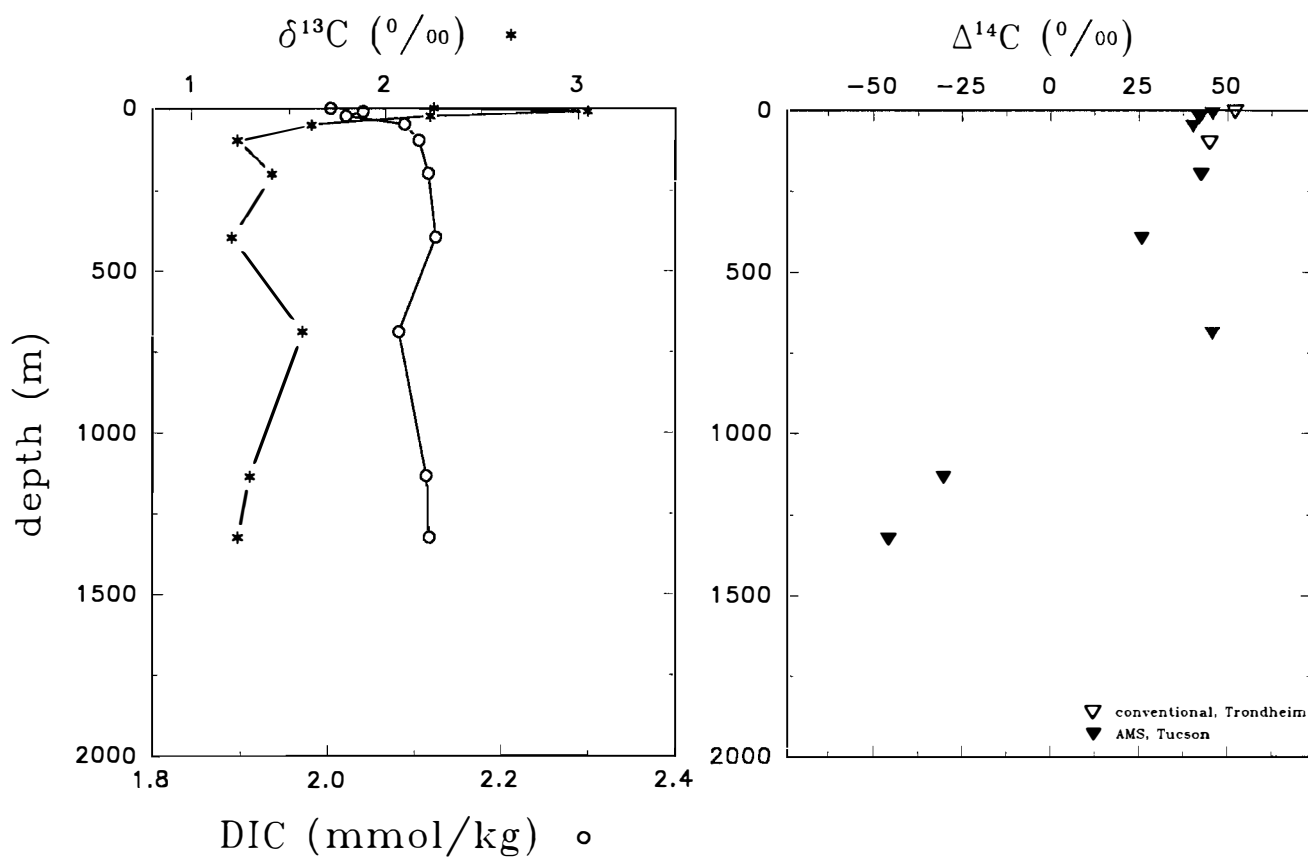
AA - AMS, Tucson.

Position: 69°30.54'N 14°49.84'W

Aug 10, 1990

Bottom depth: 1380 m

GS17



Position: 71°07.97'N 07°29.36'W

GS18

Sta.no. 1080 R/V G.O.Sars

Sample no.	Depth m	Temp. °C	Salinity psu	DIC(CO ₂) o mmol/kg	δ ¹³ C ‰	Δ ¹⁴ C ‰
GS18-1a	0	5.414	34.338	2.074	1.725	
GS18-1b	4					37.9 ± 4.5 T
GS18-2	25	1.160	34.533	2.096	1.224	
GS18-3	100	0.343	34.767	2.091		33.3 ± 5.5 T
GS18-4	200	0.465	34.841	2.133		
GS18-5a	395	-0.014	34.858	2.127	1.065	
GS18-5b	500					22.2 ± 4.7 T
GS18-6	690	-0.318	34.886	2.115	4.032	13.1 ± 4.0 AA
GS18-7a	985	-0.562	34.901	2.126	1.026	-19.2 ± 3.6 AA
GS18-7b	1000					120.2 ± 6.2 T *
GS18-8a	1480	-0.802	34.911	2.152	1.068	
GS18-8b	1500					-34.7 ± 4.0 T
GS18-9	1775	-0.854	34.913	2.119	1.248	-36.2 ± 4.4 AA
GS18-10a	1970	-0.892	34.912	2.145	0.862	
GS18-10b	2000					-42.8 ± 4.2 T

o - seawater stored 74 to 86 days (GS18-4 stored 150 days) before treatment (DIC).

♦ - value out of range.

T - conventional, Trondheim.

AA - AMS, Tucson.

Samples collected in July/Aug 1989, R/V G.O.Sars:

Position: 71°08'N 07°30'W

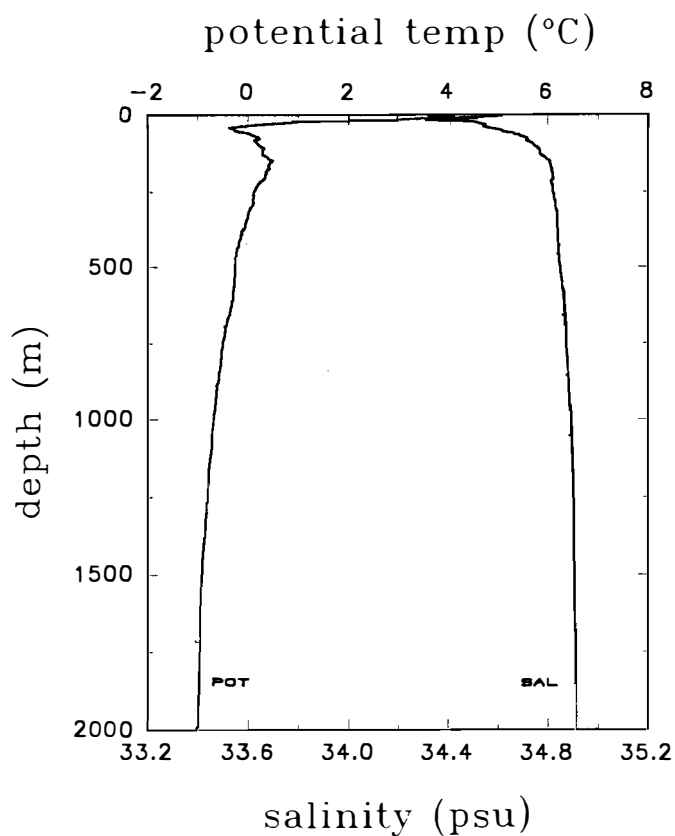
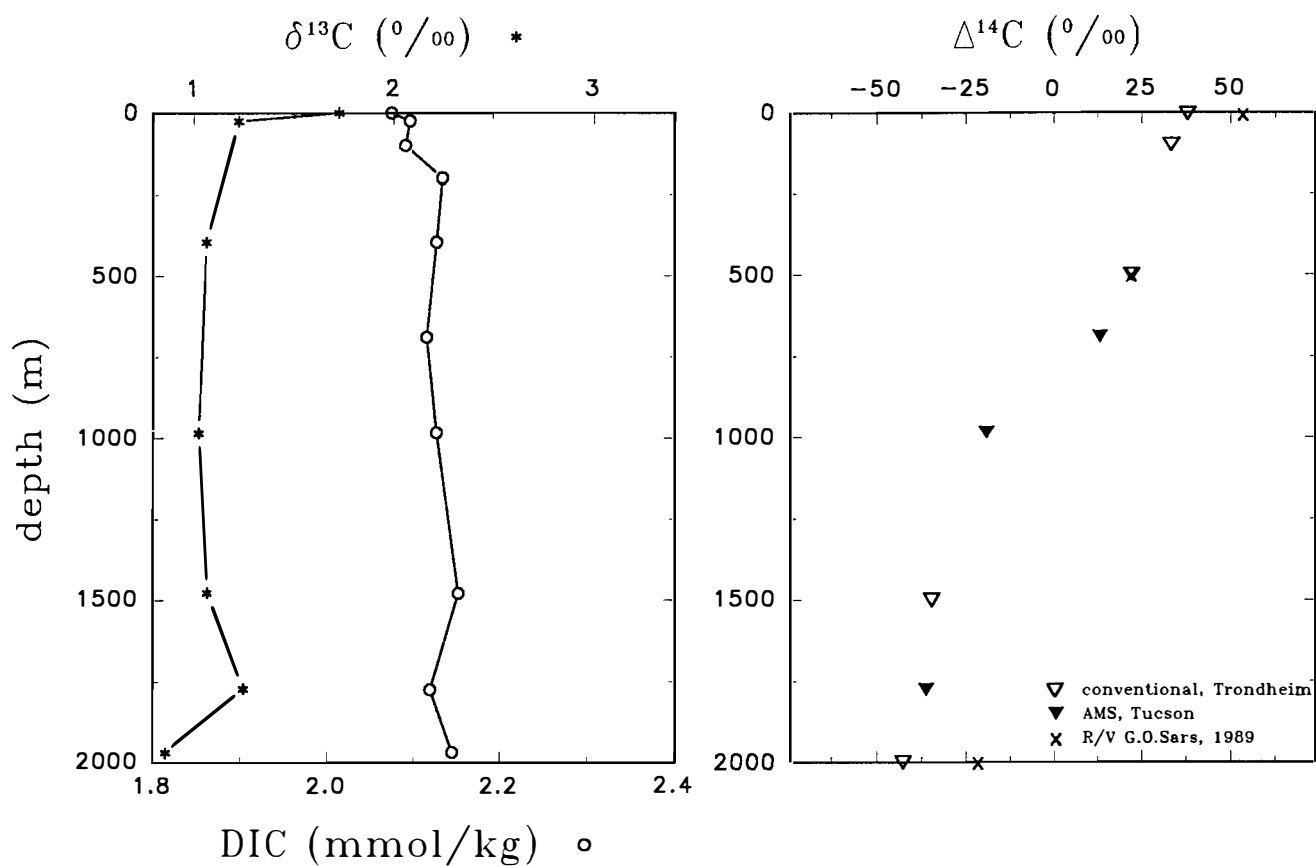
Sample no.	Depth m	Δ ¹⁴ C ‰
GS-5	4	53.3 ± 4.3 T
GS-6	500	22.0 ± 4.6 T
GS-7	2000	-21.7 ± 4.3 T

Position: 71°07.97'N 07°29.36'W

Aug 11, 1990

Bottom depth: 2180 m

GS18



Position: 69°57.42'N 09°36.11'E

GS19

Sta.no. 1089 R/V G.O.Sars

Sample no.	Depth m	Temp. °C	Salinity psu	pH	DIC(CO ₂) o mmol/kg	DIC(CO ₂) o mmol/kg	δ ¹³ C ‰	Δ ¹⁴ C ‰
GS19-1a	4							69.9 ± 3.7 T
GS19-1b	5	12.190	34.761	8.12	1.999	2.035	2.196	
GS19-2	25	8.211	35.014	8.09	2.061	2.099	1.541	61.0 ± 6.7 AA
GS19-3	100	7.244	35.163	7.99	2.097	2.138	1.156	56.1 ± 4.8 T
GS19-4a	395	4.788	35.043	7.94	2.106		1.090	
GS19-4b	500							48.2 ± 3.5 T
GS19-5	690	2.394	34.961	8.05			1.078	41.1 ± 7.1 AA
GS19-6	985	-0.188	34.887	7.89	2.109	2.169	1.080	-9.8 ± 7.0 AA
GS19-7	1480	-0.745	34.907	7.99	2.107	2.153	1.274	-31.7 ± 6.6 AA
GS19-8	1970	-0.886	34.912	7.9	2.113	2.081	1.337	-49.6 ± 6.6 AA
GS19-9	2460	-0.906	34.911	7.96	2.127		1.264	-46.1 ± 6.7 AA
GS19-10	2705	-0.896	34.911	7.89	2.114	2.140	1.283	171.9 ± 4.6 AA

o - treated immediatley (see figure).

o - parallel samples treated after 147 to 148 days.

A parallel sample of GS19-2 was stored in 87 days, wich gave a DIC value of 1.985 mmol/kg.

T - conventional, Trondheim.

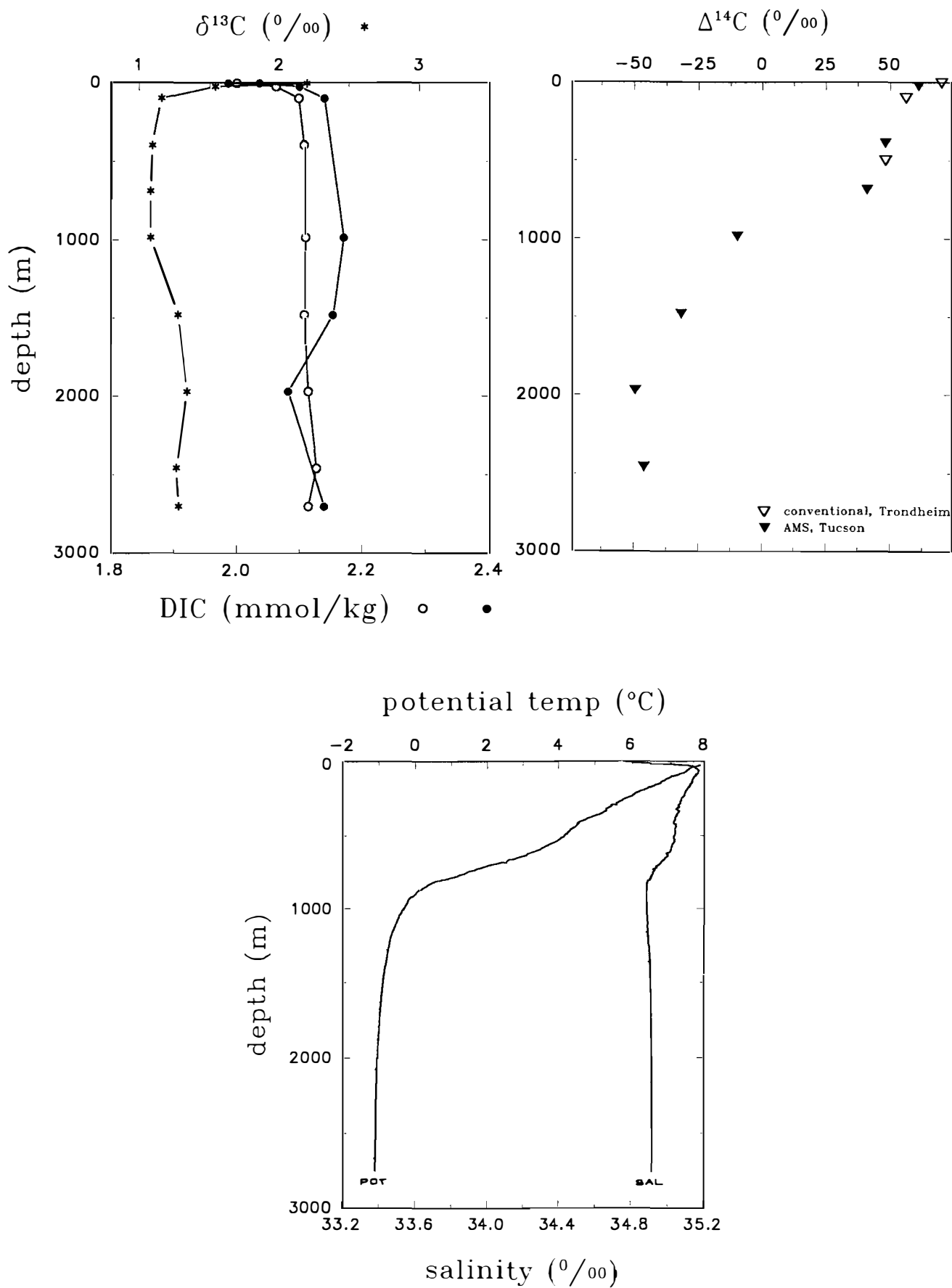
AA - AMS, Tucson.

Position: 69°57.42'N 09°36.11'E

Aug 13, 1990

Bottom depth: 2840 m

GS19



Position: 77°43.0'N 32°30.0'E

LA1

July 21, 1990 R/V Lance

Sample no.	Depth m	Temp. °C	pH	DIC(CO ₂) mmol/liter	$\Delta^{14}\text{C}$ ‰
LA1-1	4	2.7	8.14	1.865	66.3 ± 4.4 T

O₂-, salinity- and $\delta^{13}\text{C}$ values were not measured at this position.
T - conventional, Trondheim.

Position: 79°01'N 41°54'E

LA4

July 27, 1990 R/V Lance

Sample no.	Depth m	Temp. °C	DIC(CO ₂) mmol/liter	$\delta^{13}\text{C}$ ‰	$\Delta^{14}\text{C}$ ‰
LA4-1	5	3.84	1.785	2.284	65.1 ± 3.8 T

O₂-, pH- and salinity values were not measured at these positions.
T - conventional, Trondheim.

Position: 69°30.05'N 07°30.55'E

GS15

Aug 7, 1990 R/V G.O.Sars

Sample no.	Depth m	Temp. °C	pH	DIC(CO ₂) mmol/liter	$\Delta^{14}\text{C}$ ‰
GS15-1a	4	11.925		2.112	117.5 ± 3.9 T
GS15-1b	4	11.925	7.9	1.997	

O₂-, salinity- and $\delta^{13}\text{C}$ values were not measured at this position.
T - conventional, Trondheim.

SAMPLES COLLECTED DURING SUMMER 1989:

Table showing ^{14}C results from samples collected in July - August 1989 with the research vessel G.O.Sars:

Sample no.	Position	Depth m	$\Delta^{14}\text{C} \text{‰}$
GS-1	63°11.5'N 03°24'E	4	46.3 ± 4.2 T
GS-2	64°00'N 0°00'E	4	49.6 ± 4.5 T
GS-3	"	500	36.0 ± 4.3 T
GS-4A	"	2500	-36.6 ± 4.1 T
GS-4-B	"	2500	-37.0 ± 5.0 T
GS-5	71°08'N 07°30'W	4	53.3 ± 4.3 T
GS-6	"	500	22.5 ± 4.6 T
GS-7	"	2000	-21.7 ± 4.3 T
GS-8	70°59.94'N 13°49.92'W	4	61.4 ± 4.3 T
GS-9	69°00'N 09°53'W	4	55.3 ± 3.6 T
GS-10	"	450	18.5 ± 6.3 T
GS-13	69°00'N 18°52'W	4	90.0 ± 4.7 T

T - conventional, Trondheim.

Table showing ^{14}C results from samples collected in Juni - July 1989 with the research vessel Håkon Mosby:

Sample no.	Position	Depth m	$\Delta^{14}\text{C} \text{‰}$
MO-1	74°10'N 06°15'E	2.5	48.8 ± 4.2 T
MO-2	76°06'N 01°33'E	100	34.8 ± 6.5 T
MO-3	77°08'N 00°01'E	2000	-21.1 ± 4.6 T
MO-4	75°00'N 05°00'W	450	8.1 ± 4.7 T
MO-5	"	1000	-11.4 ± 4.3 T
MO-6	75°00'N 02°30'W	2000	-26.6 ± 4.7 T
MO-7	71°00'N 04°00'E	570	66.3 ± 4.7 T
MO-8	"	1970	-8.9 ± 3.9 T

T - conventional, Trondheim.

